

FABRICATION OF SENSITIVE HIGH  $T_c$  BOLOMETERS\*

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The rapid change of resistance with temperature of high quality films of high  $T_c$  superconductors can be used to make resistance thermometers with very low temperature noise. Measurements on c-axis YBCO films have given a spectral intensity of temperature noise less than  $4 \times 10^{-8}$  K/Hz<sup>1/2</sup> at 10 Hz. Consequently, the opportunity exists to make useful bolometric infrared detectors that operate near 90 K which can be cooled with liquid nitrogen. This talk will summarize the fabrication and measurement of two bolometer architectures. The first is a conventional bolometer which consists of a 3000 Å thick YBCO film deposited *in situ* by laser ablation on top of a 500 Å thick SrTiO<sub>3</sub> buffer layer on a {1012} Al<sub>2</sub>O<sub>3</sub> substrate. The sample was lapped to 20 μm thickness and diced into 1x1 mm<sup>2</sup> bolometer chips. Gold black smoke was used as the radiation absorber. The voltage noise was less than the amplifier noise when the film was current biased. Optical measurements gave an NEP of  $5 \times 10^{-11}$  W/Hz<sup>1/2</sup> at 10 Hz. The second architecture is that of an antenna-coupled microbolometer which consists of a small ( $5 \times 10$  μm<sup>2</sup>) YBCO film deposited directly on a bulk substrate with a low thermal conductance (YSZ) and an impedance matched planar lithographed spiral or log-periodic antenna. This structure is produced by standard photolithographic techniques. Measurements gave an electrical NEP of  $4.7 \times 10^{-12}$  W/Hz<sup>1/2</sup> at 10 kHz. Measurements of the optical efficiency are in progress. The measured performance of both bolometers will be compared to other detectors operating at or above liquid nitrogen temperatures so as to identify potential applications.

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# **Fabrication of Sensitive High $T_c$ Bolometers**

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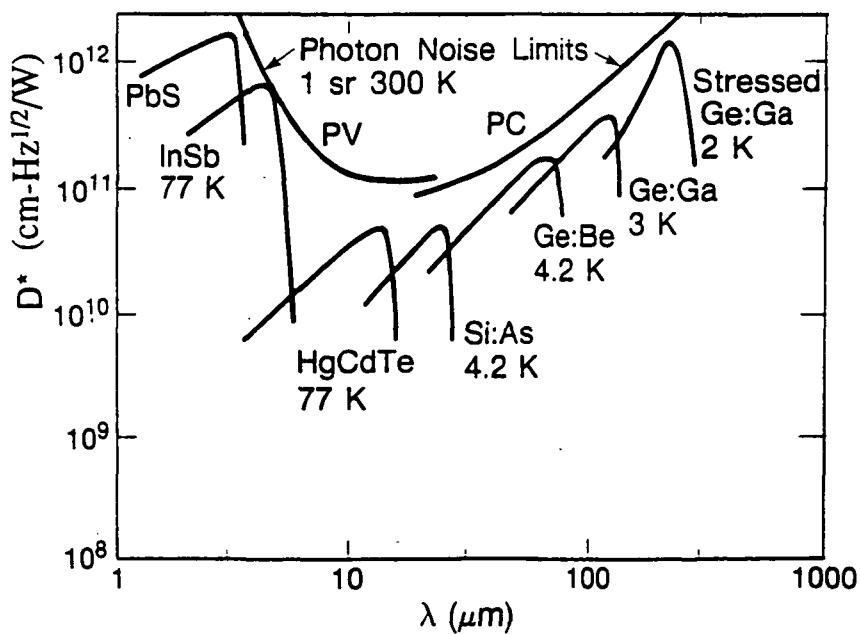
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# Outline

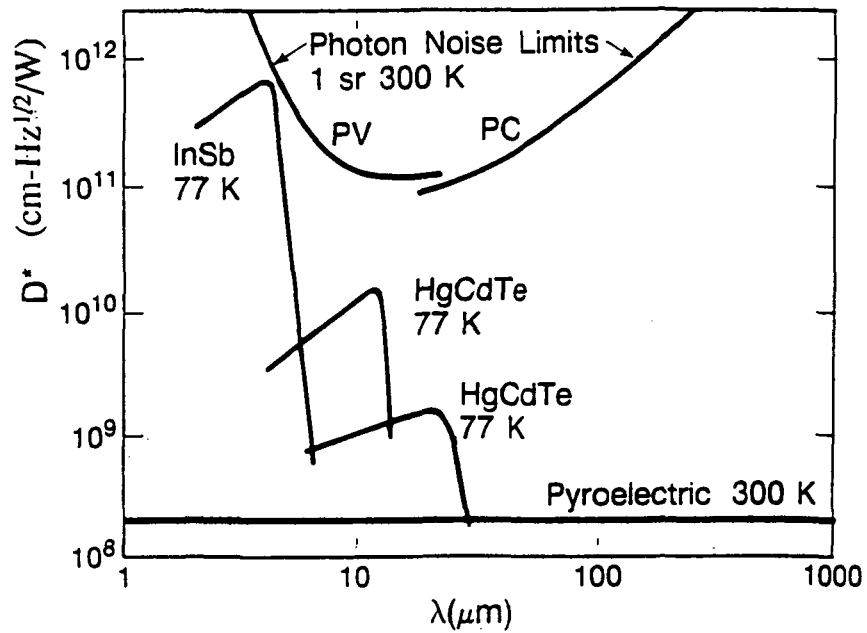
- Motivation and applications
- Conventional composite bolometer
- Microbolometer
- Conclusions

## High background applications

Performance ( $D^* = \text{AREA}^{1/2}/\text{NEP}$ ) of commercial photon detectors viewing 300K source.

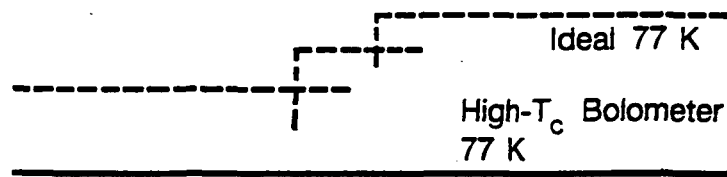


## Performance available at or above 77K



Applications above 77K:

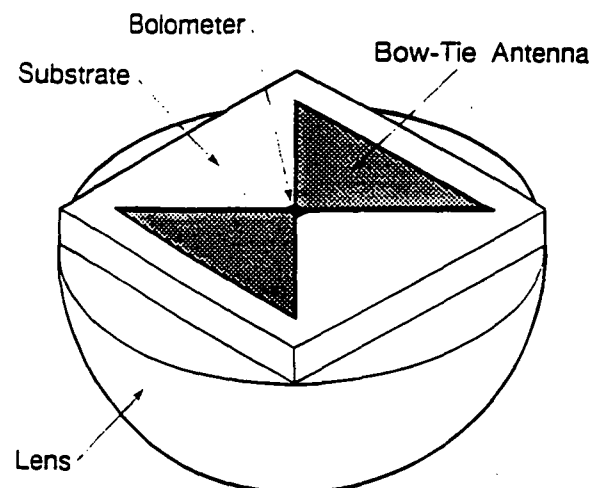
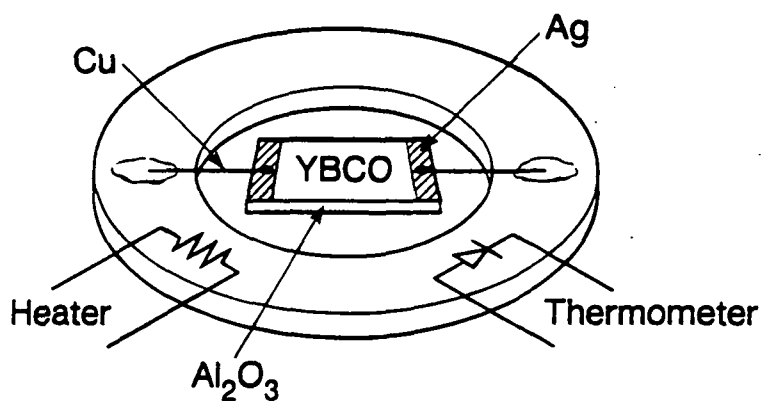
- Laboratory IR spectrometers
- Earth observations from space



P. L. Richards et al, *Appl. Phys. Lett.* 54, 283 (1989).

# Elements of high $T_c$ infrared bolometers

	<u>Conventional Bolometer</u>	<u>Microbolometer</u>
Substrate	sapphire	yttria stabilized zirconia (YSZ)
Radiation absorber	gold black Bi film	antenna-coupled YBCO
Thermometer $R(T)$	YBCO	YBCO
Thermal conductance $G$	Cu leads	thermal spreading resistance



## The high $T_c$ conventional bolometer

- Easy to make one that "works".
- Hard to get useful sensitivity.
- Good ones can be made now.
- Materials needs very specific.
- Low-noise and high  $\frac{1}{R} \frac{dR}{dT}$ .
- Proper optimization.

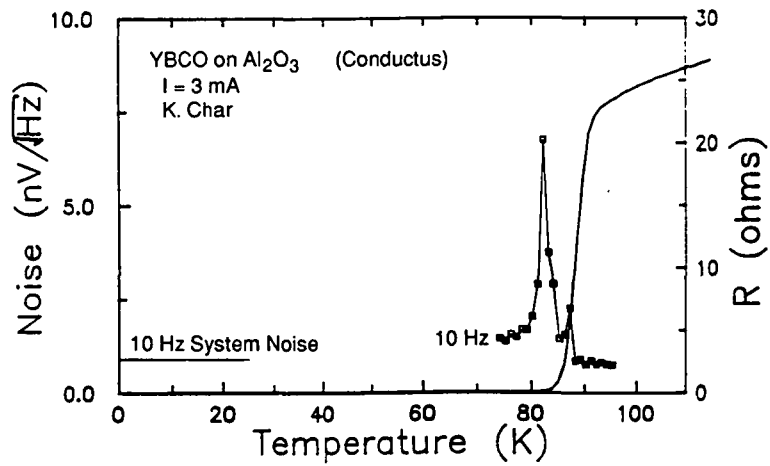
## Fabrication

- Substrate  $1 \times 1 \text{ mm}^2$ ,  $20 \text{ }\mu\text{m}$  thick,  $\{ 1\bar{1}02 \}$  sapphire.
  - Low specific heat
  - Strong
  - YBCO compatible
- Laser ablate  $3000 \text{ }\text{\AA}$  YBCO on a  $500 \text{ }\text{\AA}$   $\text{SrTiO}_3$  buffer layer on  $6 \times 6 \times 0.5 \text{ mm}^3$  sapphire.
- Sputter clean YBCO surface and sputter deposit Ag electrical contacts.
- Polish and dice.

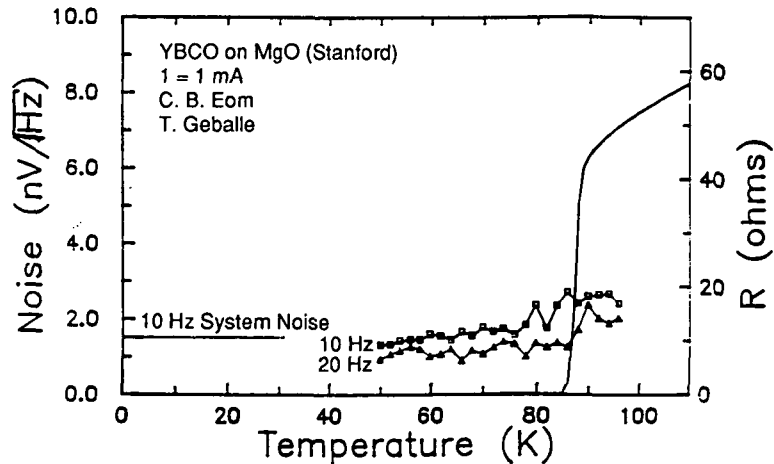
## Sensitivity $\Rightarrow$ YBCO film quality

high  $\frac{1}{R} \frac{dR}{dT}$ , low noise

- Laser ablating YBCO on sapphire gives sharp resistive transitions (K. Char et al, *Appl. Phys. Lett.*, 56, 785 (1990)).
- But there is excess voltage noise near  $T_c$  under current bias in these films.



- Using the  $500\text{\AA}$   $\text{SrTiO}_3$  buffer layer  $\Rightarrow$  reduced voltage noise.



## Bolometer optimization

Given:  $\frac{1}{R} \frac{dR}{dT}$ ,  $C$  -- heat capacity

Pick:  $I$  -- current bias  
 $R$  -- operating resistance  
 $G$  -- thermal conductance  
 $\omega$  -- chopping frequency

$$NEP = \left( 4kT^2G + \frac{4kTR + V_{amp}^2 + V_{1/f}^2}{|S|^2} \right)^{1/2}$$

$$S = I \frac{dR(T)}{dT} |G + i\omega C|^{-1}, \quad I^2 R < 0.3 G \delta T \quad \text{for stability.}$$

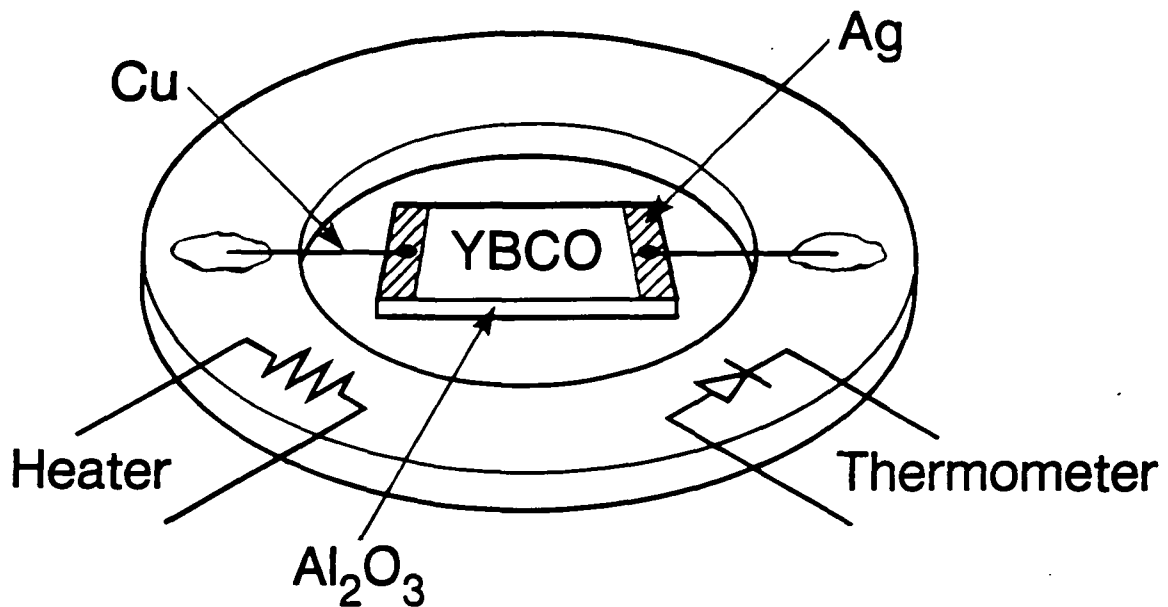
$\delta T$  -- transition width

For a sapphire bolometer:

$$\begin{array}{ll} \omega/2\pi = 10 \text{ Hz} & 1 \times 1 \times 0.02 \text{ mm}^3 \text{ sapphire} \\ \delta T = 0.5 \text{ K} & NEP \leq 10^{-11} \text{ W/Hz}^{1/2} \end{array}$$



## Measurements

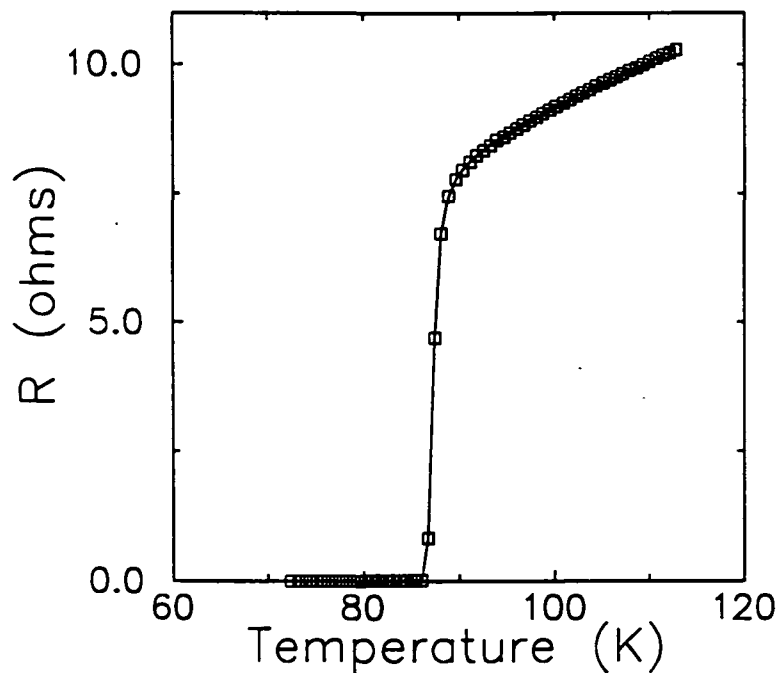


Typical Size  $1 \times 1$  mm

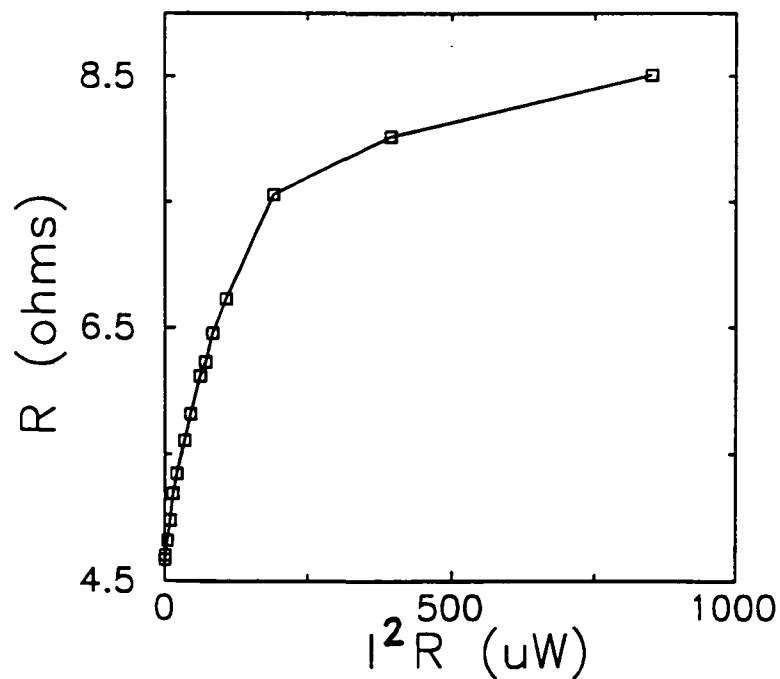
- $R(T)$  and load curve  $\Rightarrow S_{\text{electrical}} = 26 \text{ V/W}$ , 10 Hz
- Chopped He-Ne laser  $\Rightarrow S_{\text{optical}} = 22 \text{ V/W}$ , 10 Hz
- At present, noise is amplifier limited  $\Rightarrow \text{NEP} = 5 \times 10^{-11} \text{ W/Hz}^{1/2}$ , 10 Hz

# Electrical measurements

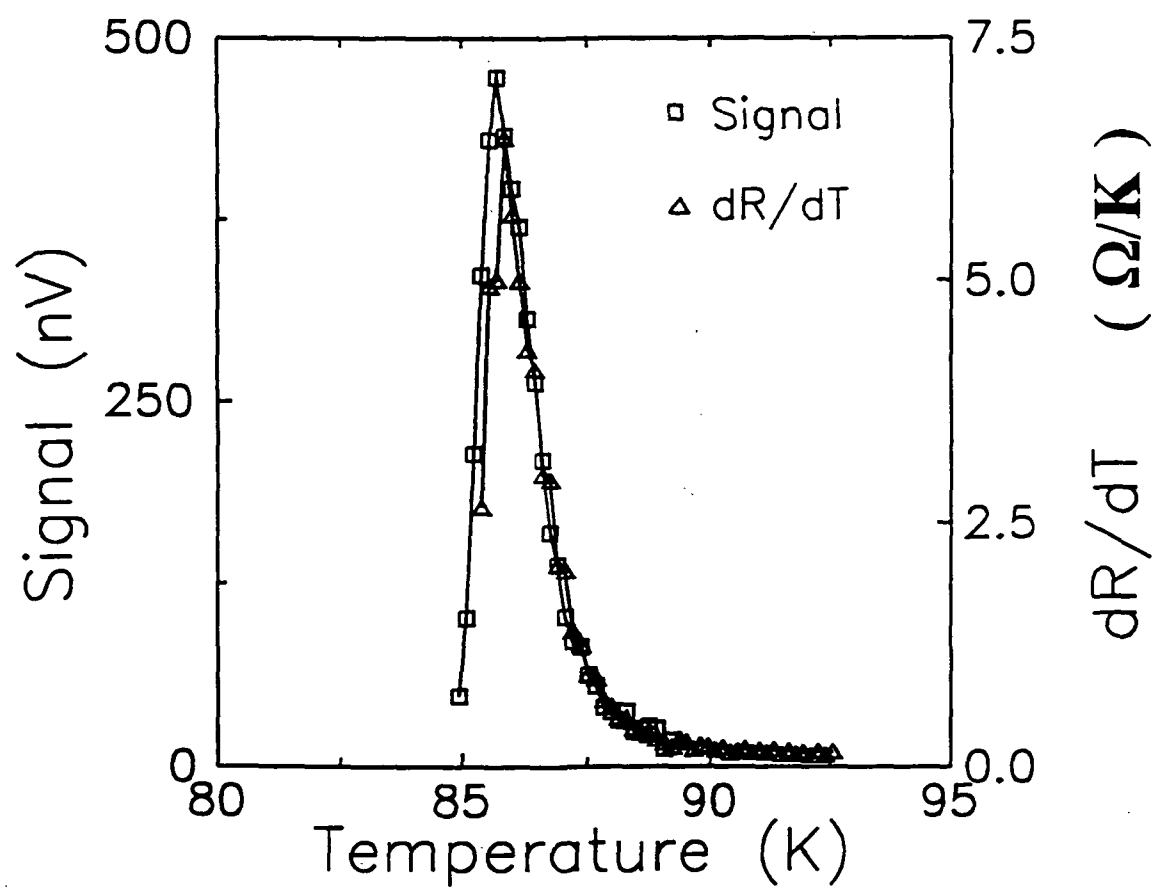
## Bolometer $R(T)$

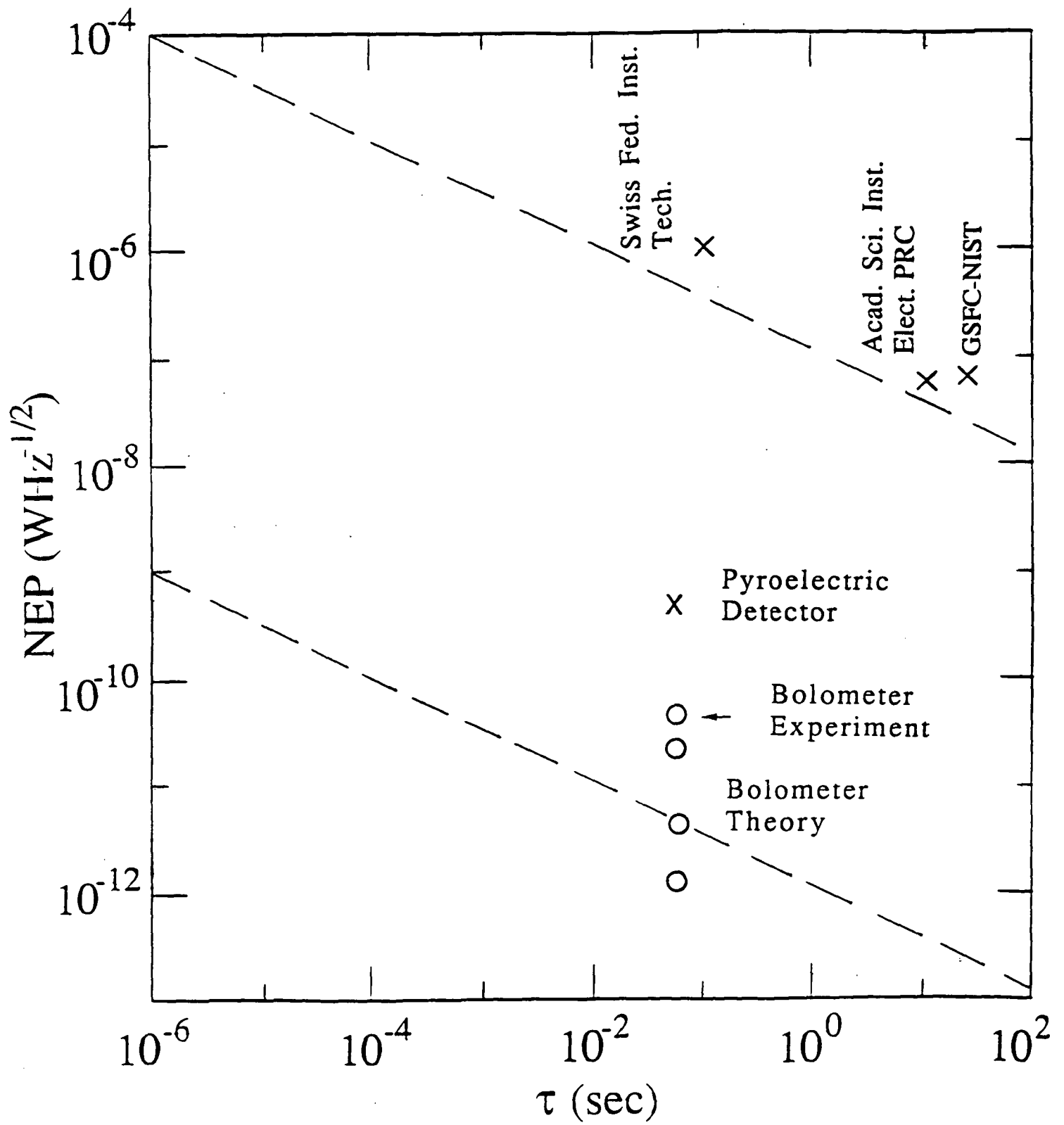


## Load Curve



## Optical response





XBL 903-5434

# High $T_c$ Microbolometer

Sensitive and fast

- Small area ( $A \approx 5 \mu\text{m}^2$ )
- Deposited directly on thick substrate
- Only small volume of substrate contributes thermally ( $V \approx 10 \mu\text{m}^3$ )
- $\text{NEP} \propto A^{1/4}$
- Response time  $\propto A$
- Couple directly  $\lambda < 2 \mu\text{m}$
- Couple with antenna  $\lambda > 100 \mu\text{m}$
- Array compatible fabrication

Qing Hu and P. L. Richards, *Appl. Phys. Lett.* **55**, 2444 (1989).

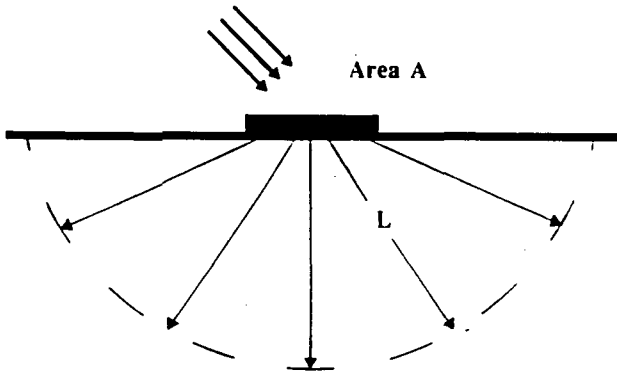
Idea from:       Hwang, Schwarz, Rutledge  
                      Neikirk, Lam, Rutledge  
                      Rutledge, Neikirk, Kasilingam

# Microbolometer thermal response

$$\text{NEP} = (4kT^2G(f))^{1/2}, \quad G(f) = ?$$

Diffusion length

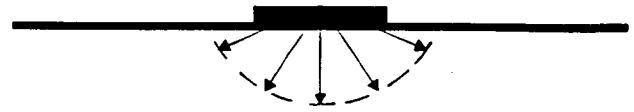
$$L = \left( \frac{\kappa_s}{c_s \pi f} \right)^{1/2}$$



$$L > \sqrt{A}$$

$$G = \sqrt{2\pi A} \kappa_s$$

$$\text{NEP} \propto A^{1/4}$$

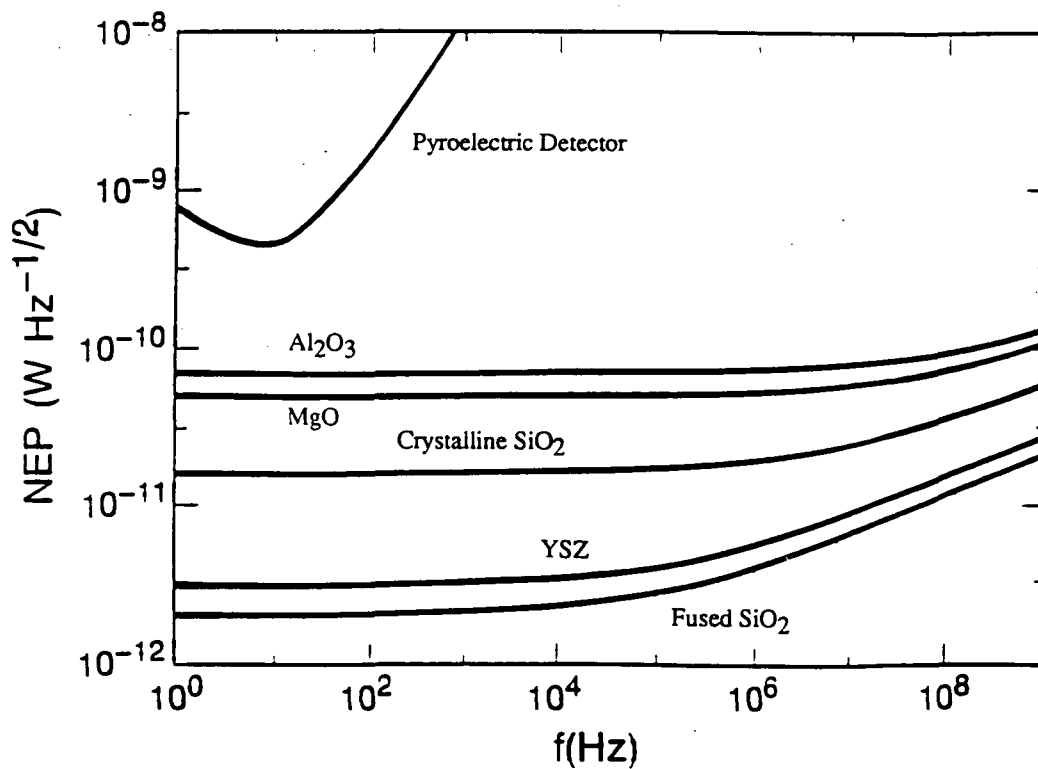


$$L < \sqrt{A}$$

$$G = \sqrt{2\pi} A (\kappa_s c_s f)^{1/2}$$

$$\text{NEP} \propto A^{1/2} f^{1/4}$$

Calculated NEP (Area =  $1 \times 5 \mu\text{m}^2$ )



## How to couple long wavelengths into a small bolometer?

- Antenna-coupled microbolometer
- Self complementary planar antenna
  - Real antenna impedance
  - Broadband response  $\lambda > 100 \mu\text{m}$
- Single mode throughput  $A\Omega = \lambda^2$



Log-Periodic Antenna



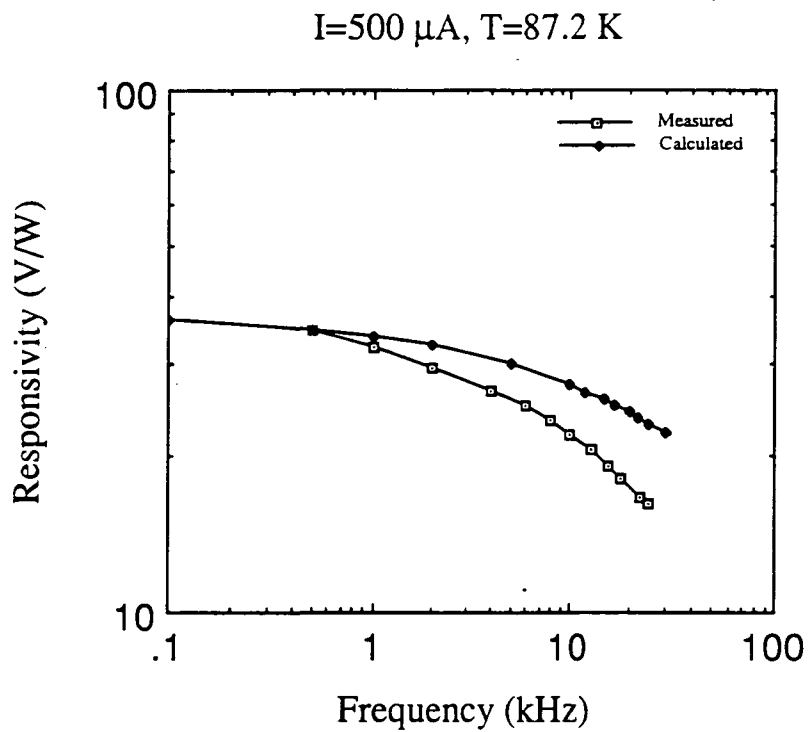
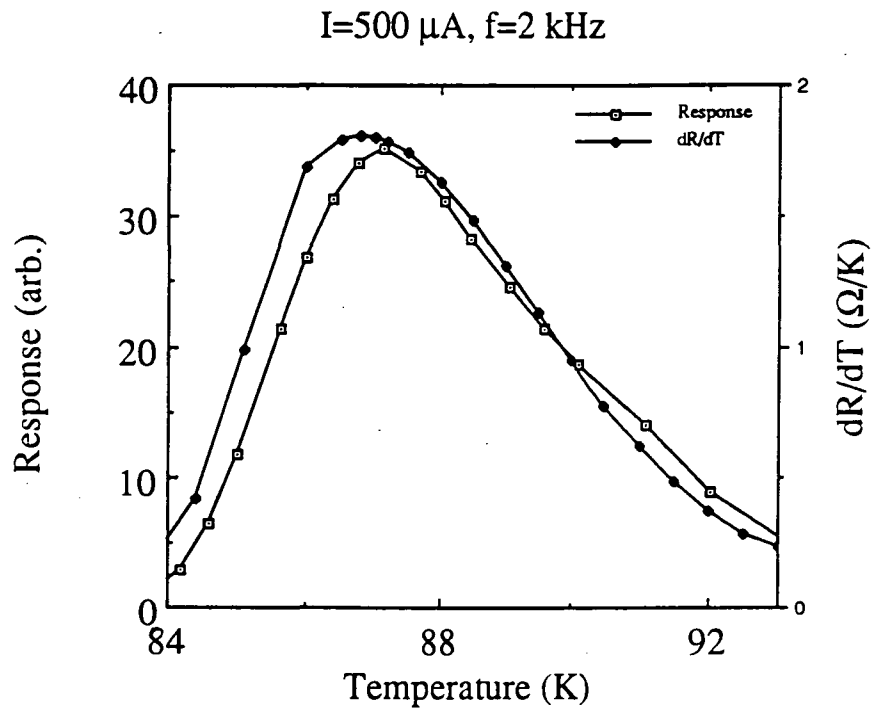
Spiral Antenna

## **Fabrication of microbolometer**

- Single target sputtered 3000 Å YBCO on YSZ.
- Pattern YBCO into 5  $\mu\text{m}$  wide strips in acid etch.
- Sputter clean YBCO surface and sputter deposit Ag.
- Wet etch Ag antenna pattern.
- Oxygen anneal 500° C for 1 hr.

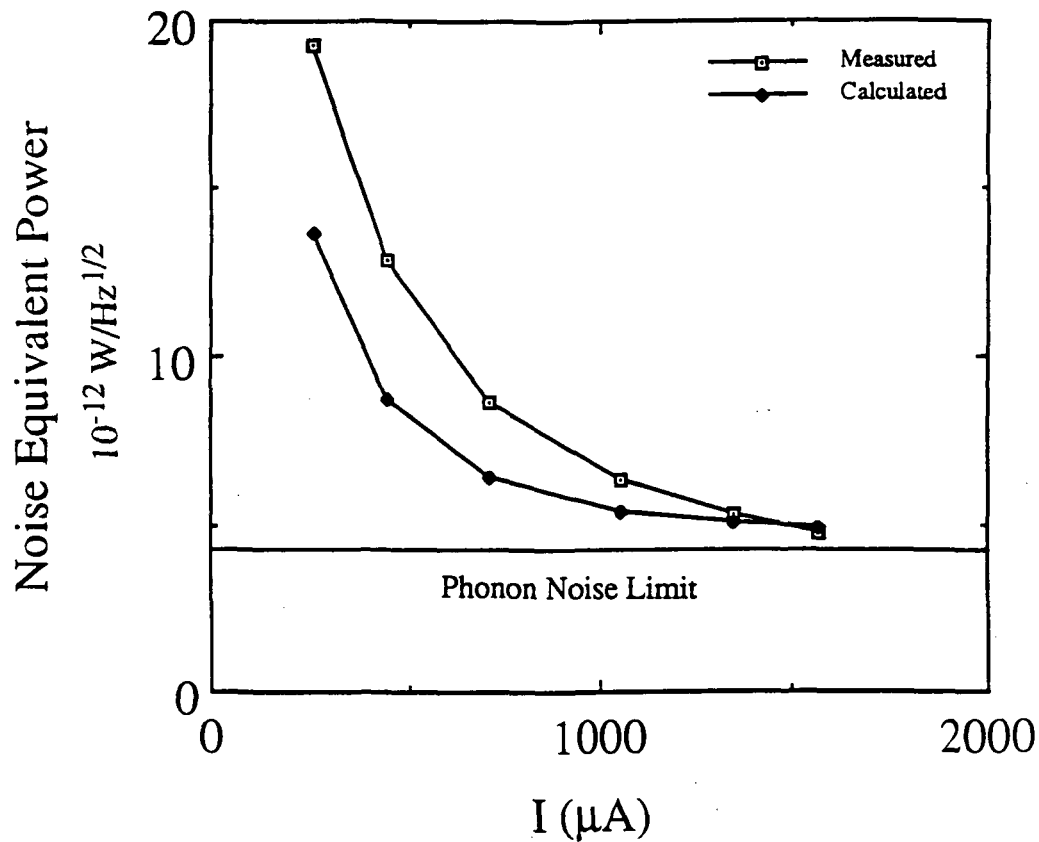


# Optical response of microbolometer

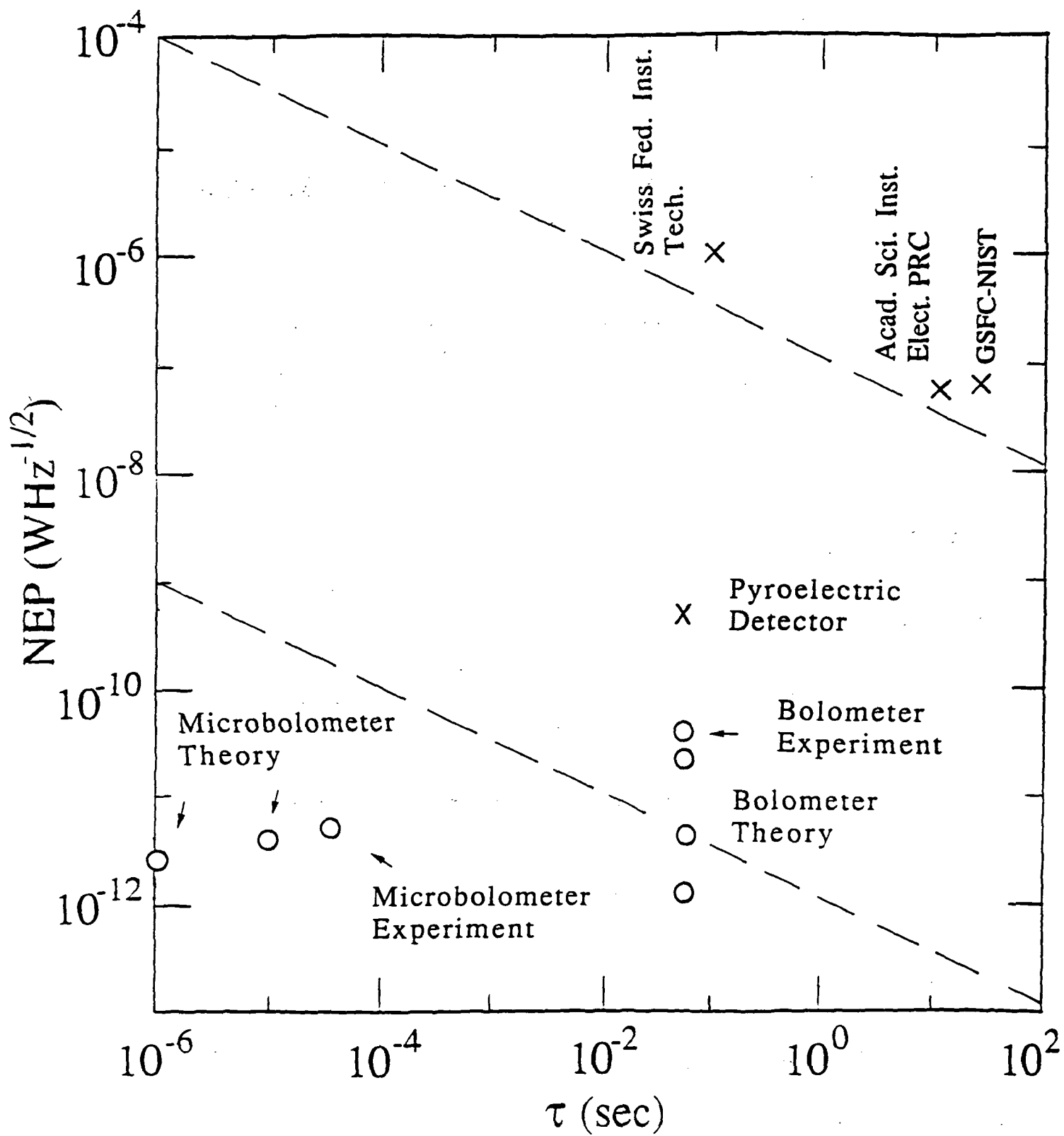


# Electrical NEP of microbolometer

$T=88.3\text{ K}$ ,  $f=10\text{ kHz}$



- Electrical NEP is G-noise limited.
- $R = 6\Omega \Rightarrow$  transformer - coupled.
- Optical efficiency measurements in progress.



XBL 903-5434

## Conclusions

- High  $T_c$  bolometers have a future for applications where cooling is limited.
- Best opportunities are for  $\lambda \geq 15 \mu\text{m}$ .
- Require highest materials quality on the "right" substrates.
- We have made conventional bolometers and microbolometers with performance approaching theoretical predictions.